ON THE PYROXENITES OF THE GRENVILLE SERIES IN OTTAWA COUNTY, CANADA.

THE pyroxenic rocks associated with the apatite deposits, and by Hunt[1] called pyroxenites, constitute an important feature of the Grenville series over considerable areas north of the Ottawa River in Canada. There has been a wide divergence of views as to their origin, some regarding them as metamorposed sediments, while others consider them to be of igneous origin. The observations of the writer support the latter view. They were made in the vicinity of High Rock, an apatite mine, situated on the right bank of the Du Lièvre River about twenty-one miles above Buckingham and forty miles north of Ottawa. The openings here cover about six hundred acres in all on the tops of the hills which rise to a height of seven hundred feet above the level of the river. The longer axes of the hills trend south 40° east parallel with the strike of the rocks of the region. The apatite occurs in veins or pockets in the pyroxenite or along the contact of the pyroxenite with dikes of syenite which cut it in various directions. As described by the writer,[2] this dike rock varies from a course-grained syenite to a rather fine-grained gneiss. As an intermediate stage there occurs at a number of places, both on the surface and associated with the apatite in the diggings, a peculiar spheroidal phase of the syenite, called "leopard rock," which is considered due to dynamic processes.

The pyroxenites usually occur in parallel bands intercalated in the quartzites, though they sometimes cut across the bedding of the latter. Fig. 2 represents the relations of these rocks as seen at one locality on the hill. The pyroxenite bands, which have the appearance of an intrusion in the quartzite, have suffered breaking and stretching, while quartzitic material has taken possession of the spaces between the disrupted blocks. Still better are these relations shown in Fig. 3. At this locality the pyroxenite appears in the main to have

[1] *Geology of Canada*, 1866, p. 185; *Chemical and Geological Essays*, p. 208.

[2] *Bulletin of the Geological Society of America*, Vol. VII, pp. 95–134.

followed the bedding of the quartzite, but in places it has broken across it and has involved considerable portions of the quartzite within itself. The rocks strike south 40° east and are cut by joints

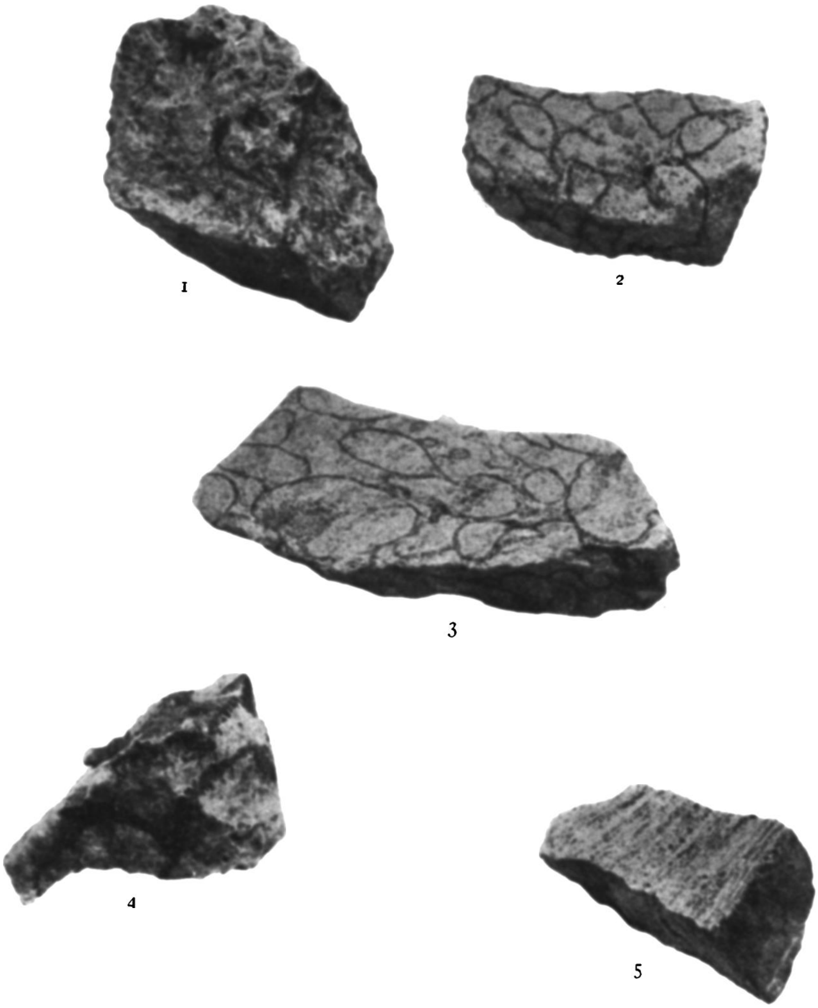

FIG. 1.—Syenite Gneiss from dikes cutting the pyroxenite at High Rock mine, Ottawa county, Canada. (1) Shows the coarse-grained phase of the Syenite, (2), (3), and (4) represent the Leopard Rock phases, and (5) the gneissic phase.

having a general direction of north 70° west. As shown at the upper left corner of the cut, the jointing is more pronounced in places along the contact with the pyroxenite. Both rocks are cut by small dikes

or stringers one-half to one inch in width, one (*a*) consisting of basic (probably hornblendic), and the other (*b*) of feldspathic material. In places masses of the pyroxenite appear as inclusions in the syenite dikes, and without close examination might easily be taken for a segregation of basic material in the syenite.

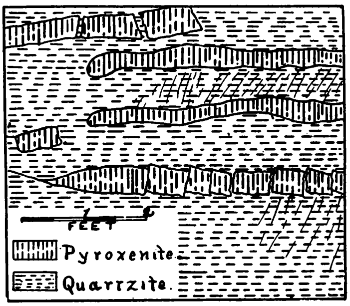

FIG. 2.—Showing pyroxenite intercalated in the quartzite.

Under the microscope the pyroxenite is shown to consist chiefly of a pale, almost colorless monoclinic pyroxene, apparently augite. It is for the most part coarsely crystallized and has a pronounced prismatic cleavage. Polysynthetic twinning in thin lamellæ parallel to the orthopinacoid (100) is frequent, giving a pronounced diallage-like appearance, probably due to the development of gliding planes as a pressure phenomenon.[1]

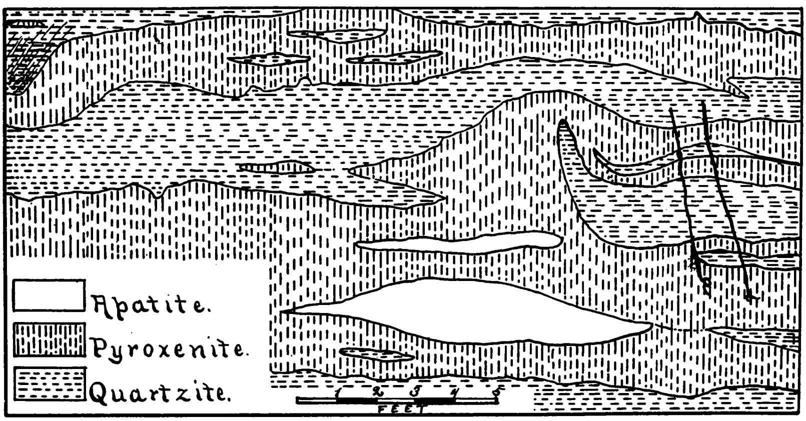

FIG. 3.—Showing the pyroxenite interbedded with the quartzite and including portions of the latter.

Further evidence of dynamic movement appears in the slight lack of correspondence in the continuation of cleavage cracks, in the bending and fracturing of lamellæ, and especially in the extinction shad-

[1] F. ZIRKEL, *Lehrbuch der Petrographie*, Vol. I, p. 612.

ows, though the last are more easily distinguished in the larger grains. The lamellæ are usually thin, varying from extreme fineness to 0.013 ^{mm} in thickness. In sections parallel to the clinopinacoid (010) the extinction angles of the lamellæ measured from 38° to 43°, and none were found to extinguish parallel, thus precluding the possibility of an intergrowth of augite and hypersthene. (Fig. 4.)

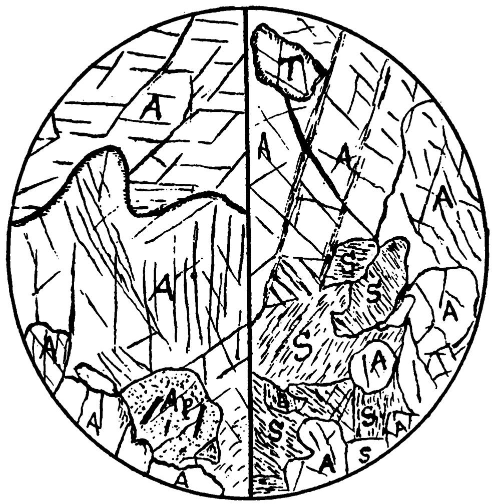

FIG. 4.—Section of pyroxenite. *A*, augite; *Ap*, apatite inclosing small prisms of zircon; *S*, scapolite; *T*, titanite.

Along with the augite there occur as minor constituents in varying, usually small, proportions, scapolite, quartz, apatite, brown mica, hornblende, and an opaque iron ore.

The scapolite has a cloudy, yellowish-gray, fibrous appearance usually, and in places occurs in considerable amount in graphic intergrowth with the augite. This is especially the case near the contact of the pyroxenite with the syenite-gneiss. An analysis of the scapolite by William Hoskins gave the following results:

SiO_2	50.230
Al_2O_3	27.207
FeO	11.123
CaO	8.175
MgO	1.732
	98.464

This indicates a high percentage of iron, with a correspondingly low showing of lime, possibly attributable to the altered condition of the material.

Apatite appears in considerable amount as irregular grains and aggregates. In some cases the pyroxenite and apatite are found in

alternating parallel lamellæ resembling eozoon and sometimes mistaken for it.

The mica is usually confined to the portions showing a laminated structure where it occurs in considerable amount along certain planes.

Titanite occurs in occasional grains, showing the usual chocolate brown color and well-marked development of gliding planes parallel to (221) characteristic of American sphenes.[1]

The hornblende which is small in amount is compact and strongly pleochroic. It is usually in close connection with the augite, and the relations of the prismatic cleavages are sometimes such as to indicate that the ortho- and clino-pinacoids of the two minerals lie parallel.

ORIGIN OF THE CANADIAN PYROXENITES.

Various opinions have been expressed as to the origin of the Canadian pyroxenic rocks. Much has been written concerning the origin of the apatite deposits which occur in them, but it is manifest that any conclusion regarding these would be shaped, in part at least, by the view held concerning the origin of the pyroxenites themselves. The occurrence of the pyroxenites in bands alternating with the quartzites and gneisses simulating bedding has led some writers to regard them as of sedimentary origin. When first used by Dr. Hunt, the term "pyroxenite" was applied both to rocks which have been recognized as intrusive, like those of Rougemont and Montarville, and to the more or less massive beds or nests of pyroxene so often intercalated in the so-called Archean limestones of New York and Canada.[2]

Concerning the latter, Hunt states that they grade, on the one hand, into granitoid orthoclase gneiss and, on the other, into limestone, and concludes that "these peculiar strata, which contain at the same time the minerals of the associated gneiss and of the limestone, may be looked upon as beds of passage between the two rocks."[3] They were regarded by this author[4] as having been deposited originally

[1] G. H. WILLIAMS, *American Journal of Science*, Series III, Vol. XXIX, p. 486.

[2] G. H. WILLIAMS, *American Geologist*, Vol. VI (1890), p. 45.

[3] T. J. HUNT, *Geology of Canada*, 1866, p. 185.

[4] *Chemical and Geological Essays*, 1891, p. 305.

as amorphous chemical sediments, which under moderate heat and pressure arranged themselves and crystallized, generating the various mineral species by a change which Gümbel designates *diagenesis*. The apatite deposits were regarded by Hunt[1] as vein formations resulting from hot-water solutions, though some were thought to occur in beds. The belief as to the vein origin of these deposits was based on the following considerations: (1) the rounded form of the apatite crystals, which he considered due to partial solution after deposition, rather than to fusion in a molten magna; (2) the manner in which one mineral incloses another, as in the case of crystalline calcite, rounded into pebbles and inclosed in the center of apatite crystals; (3) the banded structure observed in some deposits; (4) drusy cavities. The banded arrangement is not a frequent characteristic of the deposits, but is sometimes seen. Dawson considers many of the Ontario deposits as true beds and of organic origin, thus apparently postulating a sedimentary origin for the inclosing rocks,[2] though not necessarily for all of them.

Harrington, in his admirable report on the apatite-bearing veins of Ottawa county, takes the same view as to the origin of the pyroxenites, and contends that the conclusions of Brögger and Reusch concerning the eruptive origin of the apatites of Norway do not apply to the Canadian occurrences. He adds:

> The pyroxenites often contain disseminated grains of apatite, and no doubt they are the strata from which the apatite of the veins has been chiefly derived. If, as has been suggested, the apatite of these ancient strata represents material accumulated by organic agencies, then the connection of the pyroxene and apatite may be that the former constituted an ocean bottom particularly suitable for the life of the creatures which secreted the phosphatic matter.

W. Boyd Dawkins,[3] who visited this locality in 1884, adopts Harrington's conclusions, though he adds: "Were it not that it is bedded, it would pass muster as an eruptive rock." He concludes that the apatite deposits were formed in fissures in the Archean gneisses by hydrothermal or aquo-igneous action under conditions

[1] *Geology of Canada*, 1863 pp. 477, 644; *American Journal of Science*, 2d ser., Vol. XXXVII, p. 252; *Chemical and Geological Essays*, p. 208.

[2] SIR J. W. DAWSON, *Quarterly Journal of the Geological Society*, Vol. XXXII (1876), p. 289.

[3] *Proceedings of the Manchester Geological Society*, December 2, 1884.

of heat and pressure of the same general sort as that by which the rocks themselves have been affected.

On the other hand, the eruptive origin of these rocks has been upheld by various writers. In 1884, in his report on the apatite deposits, Torrence[1] guardedly states that these rocks may be due to contemporaneous intrusion. The apatite is regarded as due entirely to segregation from the pyroxene rock and never of a bedded character. In 1884 Coste[2] contends strongly for the eruptive origin of the pyroxenite, while the apatite is looked upon as possibly due to emanations accompanying or immediately following the intrusion of the igneous mass.

Dr. Selwyn subsequently supported this view, and said: "They are clearly connected for the most part with the basic eruptions of Archean date."

R. W. Ells[3] holds that, contrary to the observations of earlier writers, the pyroxene rock is not interstratified with the gneisses and quartzites, but occurs in dike-like masses and bands, which sometimes cut across the regular stratification of the associated rocks, and at other times traverse these along the bedding planes for some distance, and then abruptly change their course after the manner of other intrusives. In places, a gneissic structure is observed, but this, as in the case of the syenite, is doubtless due to great pressure. The author concludes that the apatite may be due to vapors charged with phosphoric and fluoric acids ascending along the sides of the dike.

The igneous origin of these pyroxenic rocks seems to be abundantly confirmed by their mode of occurrence at High Rock, as herein shown, and at numerous other places within the apatite district. While in general the pyroxenites extend along the bedding plane of the quartzites, they sometimes cut across the strike of these rocks after the manner of intrusions, as stated by Dr. Ells. In some places isolated lenticular masses of these rocks or a similar hornblende rock appear along the bedding plane of the quartzite, which are inexplicable except on the theory that they represent cross-

[1] *Geological Survey of Canada, Report of Progress*, 1882–83–84, Report J.

[2] *Ibid.*, 1887–88, Report S, p. 64.

[3] *Canadian Record of Science*, January, 1895.

sections of small offshoots from the main mass which have thrust themselves in between the beds of quartzite and were subsequently exposed by the planing down of the surface. Ells cites a number of cases where the pyroxenite cuts the stratified gneiss. At Little Rapids mine on Lièvre River the pyroxene dike is said to cut the banded gneiss at an angle of 30° or more. At North Star mine the

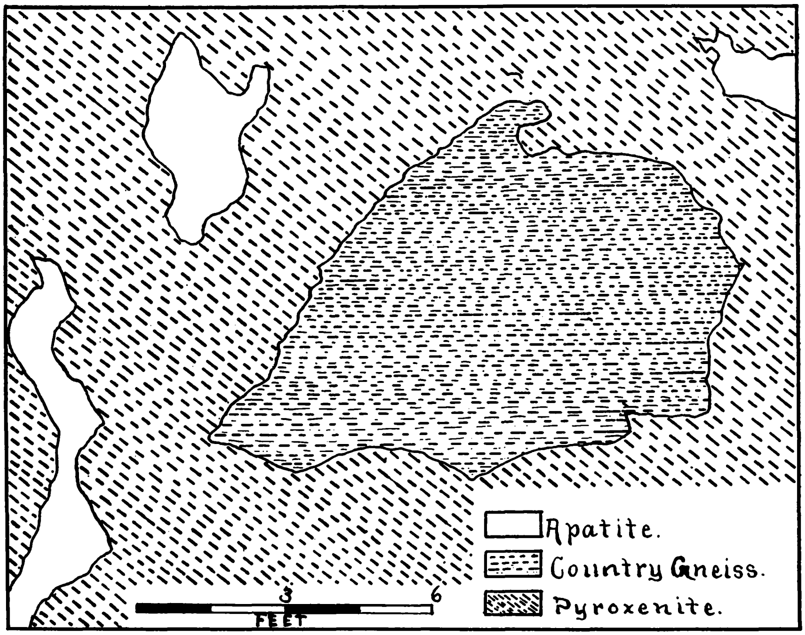

FIG. 5.—Bowlder of country rock imbedded in pyroxenite, High Rock mine, Ottawa county, Canada. (After Penrose.)

gneiss has been heaved up and bent around a portion of the dike, the contact of the two being sharply defined. A similar occurrence has been figured by Professor Penrose.[1]

That the pyroxenite should so often occur in sheets alternating with the quartzite is not strange, considering the extent of disturbance which these appear to have suffered and the more favorable conditions afforded by the bedding planes for the passage of the lava.

Further, and it would appear conclusive, evidence of the erup-

[1] R. A. F. PENROSE, "Nature and Origin of Deposits of Phosphate of Lime," *U. S. Geological Survey, Bulletin No. 46*, p. 25.

tive character of the rocks is found in the inclosures of country rock sometimes observed in them (Figs. 2 and 3). An occurrence of this kind at High Rock is noted in the above-cited report by Professor Penrose whose figure is here reproduced.

The evidence, therefore, clearly warrants the conclusion that the pyroxenic rock is intrusive. And that it represents the oldest intrusive is shown by the manner in which it is cut by the later intrusions of syenite and diorite, or so-called "trap."

NOMENCLATURE.

As heretofore stated, the term "pyroxenite" was first used by Dr. Hunt for an intrusive rock composed mostly of pyroxene with magnetite and ilmenite from Mount Royal and other places in Canada.[1] Later[2] he applied the name to the pyroxenic member intercalated in the limestones and quartzites of the apatite district, a rock generally regarded as having no genetic relationship with the first. Among the Canadian geologists it has come to be applied almost exclusively to the latter rock. Lacroix uses the term *gneiss à pyroxène et à wernerite* for a rock of essentially the same character from Brittany.[3] In the later work[4] Lacroix conforms to the German and English usage of calling this rock an "augite gneiss." These gneisses are said to occur in the upper part of the gneiss system, and are usually characterized by scapolite in greater or less abundance as in the Canadian rocks. The term "pyroxenite," which had previously been applied to these occurrences, is reserved by this author for rocks composed exclusively of pyroxene.

In 1890 G. H. Williams[5] used Hunt's term in its original signification for basic intrusions occurring in the eastern portion of the Piedmont Plateau in Maryland. These rocks are of a somewhat different type from the Canadian rocks, in that they are composed chiefly of an orthorhombic instead of a monoclinic pyroxene. Williams speaks approvingly of Lacroix's substitution of the term

[1] *Geology of Canada*, 1863, p. 667.

[2] *Catalogue of Canadian Rocks at Paris Exposition*, 1862; *Geology of Canada*, 1863–66, pp. 185–226.

[3] *Bulletin de la Société française de Mineralogie*, Vol. X (1887), p. 288.

[4] *Ibid.*, Vol. XII (1889), p. 83.

[5] *American Geologist*, Vol. VI (1890), p. 35.

"pyroxene-gneiss" for the French equivalents of the pyroxenic rocks occurring in beds or nests in the Grenville series, and contends that the Canadian use of the term "pyroxenite" for these rocks should be abandoned and the name restricted to non-feldspathic plutonic rocks free from olivine. The term is thus made a class designation co-ordinate with "peridotite," given by Rosenbusch to the corresponding olivine-bearing series, and the author says that its use as a designation for any rocks except those of igneous origin should be abandoned. As nearly all the Canadian pyroxenites were regarded by Williams, evidently on the authority of Hunt and others, as metamorphosed sedimentaries, they were excluded from the list. Zirkel[1] adopts Williams' classification, and includes these rocks with Lacroix's wernerite rocks under the pyroxene gneisses of the crystalline schists, apparently, though without distinct reference.

Pyroxenic rocks with augite as the chief basic mineral are not of common occurrence. Clements has described one from Alabama[2] which seems to be closely allied to these Canadian pyroxenites. In a comparison of the Ottawa pyroxenites with younger rocks, manifestly consideration must be given to the long period of time during which the former have been subjected to mountain-making forces.

As the result of this study we conclude:

1. That these pyroxenic rocks of Ottawa county were intruded into the overlying sedimentary beds at considerable depths, and solidified originally as a coarse-grained pyroxenite consisting chiefly of augite, but approaching the gabbro end of the series.

2. That, through the changes effected by pressure and metasomatic processes, whereby original structures have in large part disappeared, the rock should now be classed with the pyroxenite-gneisses.

3. That the apatite deposits associated with these rocks were due to fumarolic action at the time of the intrusion of the pyroxenites, and also, to a greater extent possibly, to that attending the later intrusions of syenite.

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[1] *Lehrbuch der Petrographie*, Vol. III, p. 149.

[2] *Bulletin 5*, Geological Survey of Alabama, p. 163.